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Toward a methodological knowledge based approach for partial automation of reverse engineering

Mohamed-Islem Ouamer-Ali[a]*, Florent Laroche[a], Alain Bernard[a], Sébastien Remy[b]

[a] *IRCCyN – Ecole Centrale de Nantes, 1 rue de la Noë, Nantes 44200, France*
[b] *ICD LASMIS – Université de Technologie de Troyes, 12 rue Marie Curie, Troyes 10004, France*

* Corresponding author. Tel.: +33-240-376-928; fax: +33-240-376-930. *E-mail address:* first-name.last-name@irccyn.ec-nantes.fr

Abstract

Nowadays, reverse engineering is widely spread in the manufacturing industry. The need of shorter development cycles has led to the identification of social and economic issues related to reverse engineering. The integration of a reverse engineering solution in a PLM context represents a good solution in order to shorten the development cycles, especially when it is automated. In this paper we present the issues identified in the context of METIS, a French national project aiming to provide a software solution for reconstructing large and complex mechanical assemblies and systems, through a global reverse engineering methodology combined with a knowledge management approach, and using heterogeneous data as inputs.

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Keywords: Reverse engineering ; Knowledge management ; Heterogeneous data integration; PLM.

1. Introduction

Reverse engineering has been developed as an alternative solution to define or redefine objects [1]. Nowadays, it is widely spread in the manufacturing industry. It is used for the capitalization of information and knowledge, which haven’t been collected yet. This is a critical issue for the development and evolution of products. We can list some of its applications in industry: long life products maintenance (trains, boats, aircrafts, nuclear power plants, etc.), redesign of existing products in order to improve them, competitors’ products’ analysis…

In the manufacturing industry, there is an amount of social and economic issues related to reverse engineering and its integration into the digital chain in a PLM context: shorter development cycles which lead to a drastic reduction of costs, a simplification of knowledge management related to the projects…

However, the major industrial issue lies on the improvement of existing solutions in order to respond to generic use cases [2]. The use of raw data such as digitized objects as only inputs is not sufficient to build a robust reverse engineering process. There is a need to consider the implicit and explicit knowledge. On top of that, to increase the efficiency of the process, the automation of the process has to be considered in order to address the issue related to shorter development cycles.

This paper will address the development of a reverse engineering solution partially automated, through a knowledge management approach in order to develop a generic knowledge-based reverse engineering methodology. This methodology can be adapted to different reverse engineering contexts of use, and enables lead to rich results integrating different points of view in order to increase the redesign efficiency of complex assemblies, while being fast since it would be partially automated.

After the description of the context of the research work in section 2, section 3 deals with the problem statement, while section 4 presents the proposed scientific methodology. Finally, the last section introduces the METIS project that is the application of this research.

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2. About Reverse engineering and knowledge management

2.1. Reverse engineering

Reverse engineering is the reverse process of the design activity. It basically consists on the reconstruction of design models associated to a real product [3]. The main goal of the reverse engineering is to go back to the results of the original design process in order to create a copy of the product, as shown in the figure 1 [4]. To do this, the reverse engineering process uses the knowledge extracted from the real product's characteristics analysis, combined with knowledge that concerns the manufacturing process.

Nowadays, there are several solutions dealing partially with this topic [5] [6], mainly working on the geometrical aspect of the product. In general, there are 4 main actions that are identified in the reverse engineering process [7]:

- Product scanning and data acquisition.
- Segmentation of the acquired data.
- Knowledge extraction (i.e., feature recognition).
- Reconstruction of the 3D model updated.

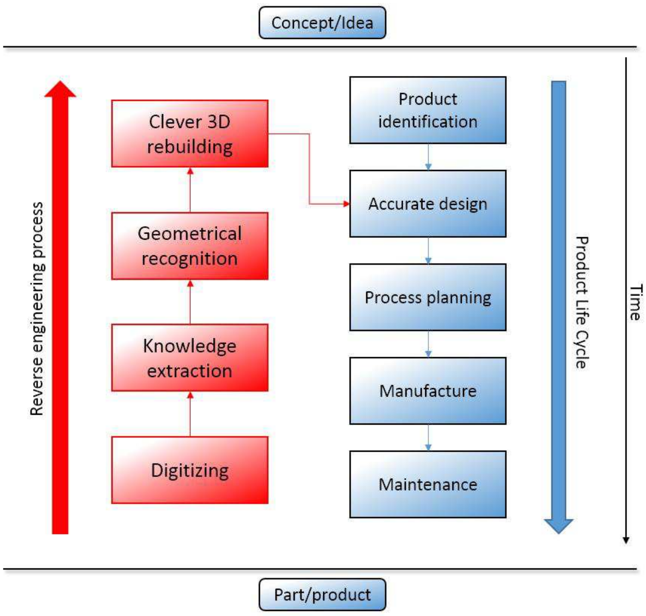

Fig. 1. The reverse engineering process connection with the product development cycle [4]

However, those approaches do not take into account the implicit and explicit knowledge related to the products, and the 3D models are frozen and do not allow flexibility. In other words, the parameters, the relationships, and the constraints that materialize the design knowledge within a 3D model are not available.

In general, research works related to reverse engineering are essentially focused on mechanical parts starting from 3D points clouds. The aim is often to recover a digital mock-up. There are several solutions that allow knowledge extraction from data. For example, in figure 2 is illustrated a solution for the association of features with points clouds [8][9] (Figure 2).

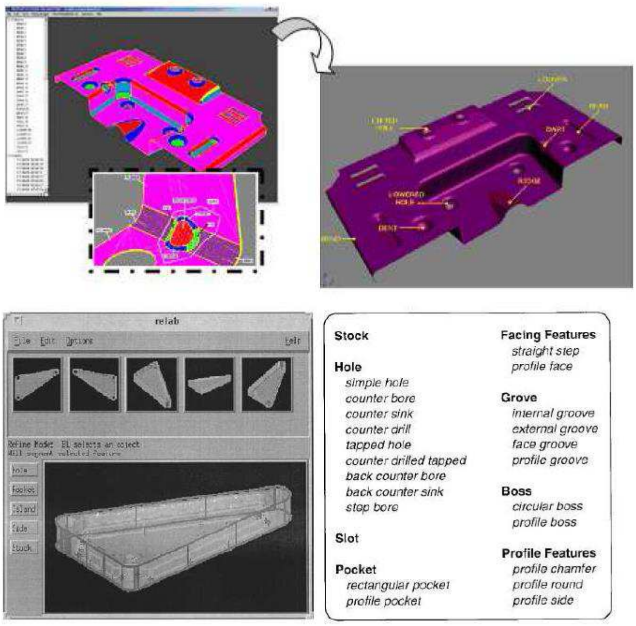

Fig. 2. Entity extraction systems. Top: Sunil & al. [8], bottom: Thompson & al. [9].

Another example is the VPERI project [10], which aims to build methodologies, tools and technologies in order to make viable and maintain systems already designed. The reverse engineering process is supported by the ASU-DAL CAD platform that allows the additions of comments virtually written on the heterogeneous data (Figure 3).

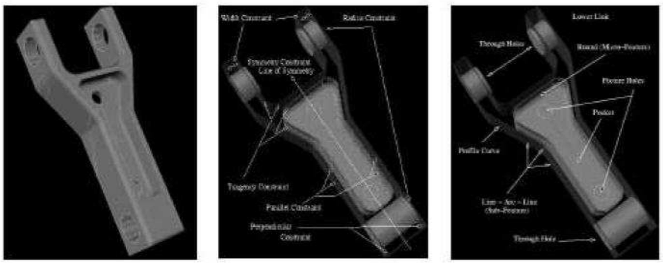

Fig. 3. Sample of the ASU-DAL interface a part [10]

In the project MERGE, the system provides a single collaborative platform in order to visualize information [11].

Acquire and process product knowledge is important to obtain a rich digital mock-up. A solution based on the functional diagram block (APTE – requirements analysis) brings to light the different flows related to the product [12].

All of those methodologies offer few possibilities of automation for the reverse engineering process, or freeze the digital mock-up, and do not consider the implicit and explicit knowledge. In fact, in the case of the VPERI project, reverse engineering is interactive but very manual, thus, tedious.

The PHENIX project brought into evidence this lack [7]. The PHENIX approach proposes a knowledge management solution in a PLM system. In this case, the reverse engineering process became partially automated, where the user selects the entities corresponding to the studied component while browsing an entities database. However, PHENIX can process only points-clouds as inputs and reverse engineer components and parts, thus do not deal with large complex assemblies and systems.

Out of the industrial context, there are an amount of works dealing with reverse engineering, such as systems that allow to obtain 3D models from heterogeneous data (pictures, points-clouds…) [13].

2.2. Knowledge management

With the increasing complexity of products, comes an increasing quantity of associated knowledge. Thus, the need to manage all the information and knowledge related to the products is crucial to the evolution of the product itself, and the evolution of the company.

Since the early 90s, considering the transformation of information and the capitalization of knowledge became a priority for companies: it is the *knowledge management*.

Knowledge management has to be considered as a system of initiatives, methods and tools, for the creation of an optimal knowledge flow for the success of the company and its clients [14]. In Asia, knowledge management is considered as an anthropocentric method where the formulation and the storage of knowledge is an extremely delicate operation: It is the *Ba* concept [15]. According to this approach knowledge management methodologies do not only consist of a data processing system, but also in the possibility to create collective knowledge.

Many research works have been initiated on the sustainability of knowledge, including implicit knowledge. This implicit knowledge is capitalized using an identified process and is transcribed into explicit knowledge.

As an example of capitalization methodologies, the Record Management standard proposes the methodology in figure 4, for the capitalisation of knowledge.

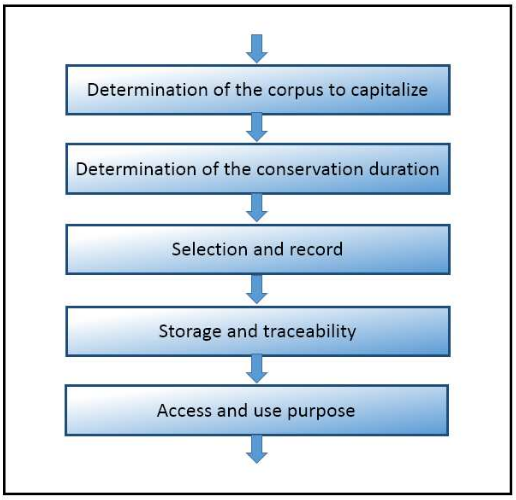

Fig. 4. Knowledge capitalization process

As this method is generic, it cannot consider the diversity of sources taken into account. In fact, many purposes could be applied to the capitalized knowledge. Consequently, there is a different method for each purpose.

In knowledge management, there are plenty of methods proposed in order to capitalize different categories of knowledge. As defined by Nonaka [15], there are 2 types of knowledge: Tacit (Implicit) knowledge and explicit knowledge. Tacit (Implicit) knowledge is subjective and experience based. It cannot be expressed in words, formulas, numbers… While explicit knowledge is objective and rational that can be expressed.

The table below shows some of the methods of knowledge capitalization. The methods are sorted by category or application.

Methods	Description	Category or Application	Ref
MKSM /MASK	Allows the mastering of complexity in knowledge management projects	Product knowledge	[16]
Common KADS	Based on the assumption that knowledge sharing is based on communication and knowledge re-creation	Implicit knowledge	[17]
KOD	A development methodology of knowledge based systems: provides collection and knowledge modelling frameworks	Product knowledge	[12]
MOKA	Knowledge formalization method for KBE/KBS application development	Implicit knowledge	[12]
REX	Feedback capitalization	Manufacture feedback	[12]
MEREX	Capitalization of knowledge extracted from best solutions	Design feedback	[12]
CYGMA	Collection, formalization and capitalization of design knowledge	Implicit knowledge	[12]
KADS	Knowledge based systems designing method	Implicit knowledge	[12]
ARDAN S Make	Capitalization and update of the experience and know-how of an organization	Implicit knowledge	[18]
KRM	Knowledge and records management	Implicit knowledge	[12]
APTE-AVT	Design choices traceability	Design traceability	[12]
Atelier FX	Capitalization of the knowledge by processing a morpho-syntactic analysis of a text	Implicit knowledge	[19]

Fig. 5. State of the art of KM methods based on the works of [Laroche 2007] [12] and refreshed with new methods

2.3. Heterogeneous data integration

In the introduction is stated the importance of implicit and explicit knowledge in order to build a robust solution for reverse engineering, in addition to raw data. In our case, raw data is heterogeneous (pictures, points-clouds, 3D models, tables…) and has to be integrated in way that enhances its processing.

Many works on the integration of heterogeneous data have been held, as an example the TSIMMIS project [20] which goal was to develop tools that facilitate the rapid integration of heterogeneous information that may contain both structured and unstructured data.

SOBA [21] is another project which aims to provide a question answering solution. For this, a system for ontology-based information extraction from heterogeneous data resources, structured or unstructured. It interlinks information extracted from different sources and process duplicate information. It integrates deep and shallow natural language processing in order to increase robustness and accuracy for the questions answering.

3. Problem statement

The integration of the knowledge management capabilities to enhance the reverse engineering process requires a conceptual framework covering different points of view. In this section, the Ishikawa method is used to put this conceptual framework through a set of 5 questions:

- What is the context of application of the reverse engineering activity or the goal aimed?

There are different contexts in which reverse engineering could be involved, such as re-engineering, re-designing, maintenance, remanufacturing.

According to each context, we have a set of goals to reach in order to fulfil the requirements needed.

To address the issue of a generic reverse engineering methodology for a partial automation, a common ground between those contexts must be found.

What are the elements that allow the design of a generic methodology for a partial automation of the reverse engineering process?

- Who is involved in the reverse engineering process?

Reverse engineering involves many actors from the company, which represent a real knowledge source. Leveraging it conventionally results in the direct intervention of the different actors. However, if the human factor is taken into account, this process is rather liable and doesn't bring the robustness needed.

Thus, there is a need to manage all the information transiting within the company ecosystem, especially knowledge.

How could we manage the capitalization of all the information and knowledge to use it in a reverse engineering context?

- Which means are needed?

In term of means, it is widely accepted that the reverse engineering process uses different processing algorithms. However, it would be wiser to consider knowledge not only as a final object (result), but also as a mean used during the reverse engineering process, and as raw material that has to be extracted from data. In fact, the reconstruction of knowledge requires knowledge already there, data represents a particular case of knowledge [12].

Thus, there is a need to create an organized knowledge structure in order to integrate it in the generic reverse engineering methodology for a partial automation purpose.

The knowledge structure would constitute a base on which lies the generic methodology. Using different algorithms to extract knowledge form raw data by comparing and detecting knowledge in the structure. Finally, it will constitute the bricks that will help building a new model according to the goals of the reverse engineering.

How could we extract relevant knowledge from raw data? And how could we structure knowledge in order to use it for the extraction?

- What are we processing?

The analysis of the elements processed in the reverse engineering process allows the identification of data broadly as raw material. Here is a list of data types that could be taken into account:

  - Images, videos.
  - Points clouds, CAD models, and digital mock-ups.
  - Tables, text.

Different processing algorithms would allow the extraction of information and knowledge from it. However at this level of abstraction, data processing is still difficult. The heterogeneity of data is a serious obstacle for its processing and integration in the context of a generic methodology of reverse engineering.

How could we integrate heterogeneous data and process it in this context?

- Is there a methodology for reverse engineering? If yes, which one?

As stated in section 2, there are many reverse engineering methodologies in the scientific literature that are designed to address certain specific needs. Several approaches dealing with the reverse engineering of small systems or components can be found. Often based on scanning solutions (Mainly 3D laser scan) [13] [22] to obtain surfaces, points clouds or meshes, or by measuring the values of different parameters directly on the parts or systems.

Those solutions are limited and don't allow to meet the needs of a global and generic approach of the reverse engineering process. The majority of the solutions are addressed with a partial vision to meet a specific need, and do not reflect the true complexity of the process. Besides, these solutions don't allow to process complex systems and assemblies, and often require a tedious work.

Which methodology is generic enough to process any kind of system?

4. Research methodology

In the previous section, five research questions were asked in order to define the problem statement. In this section, a research methodology will be brought to contribute to the resolution of the scientific problematic. For each question, we give hypothesis for solving them.

- What are the elements that allow the design of a generic methodology for a partial automation of the reverse engineering process?

A first hypothesis is that there is a set of goals that are common to all the contexts taken into account, on the condition that the goals are on the digital mock-ups. In fact, the richness of a digital mock-up is a point that have to be taken into account. For example, if the context is the re-design of a mechanical part of an engine, there is no need to reverse engineer the entire engine.

- How could we manage to capitalize all the information and knowledge to use it in a reverse engineering context?

The idea here is to use a knowledge management method to capitalize the implicit knowledge used in the design process of systems, in order to avoid knowledge loss when actors leave.

Several methods are taken into consideration to complete this task (shown in figure 5).

- How could we extract relevant knowledge from raw data? And how could we structure knowledge in order to use it for the extraction?

Using different sets of algorithms for features extraction, segmentation of points-clouds, image processing, the extraction of relevant knowledge is made possible.

On the second part, an ontology based system could be a good response structuring the knowledge.

- How could we integrate heterogeneous data and process it in this context?

The issue here is related to the interoperability of data, since it deals with heterogeneous data. In this context, there are some of the typical barriers that prevent data interoperability: A conceptual barrier represented by a difference in the semantic syntax representing information, and an organisational barrier materialized by databases management

- Which methodology is generic enough to process any kind of system?

Based on the previous works such as VPERI and PHENIX, the aim here is to extract the common points from the methodologies and complete them to obtain a generic methodology.

The first hypothesis that has been proposed is that the methodology could be raw data oriented (inputs). In fact, the semantic richness of data allows the creation of a data rating system on which the model would be based. For example: a full parameterized digital mock-up is richer than a points-cloud which in turn is richer than a picture… Using this system, we can create a methodology which guidelines are raw data.

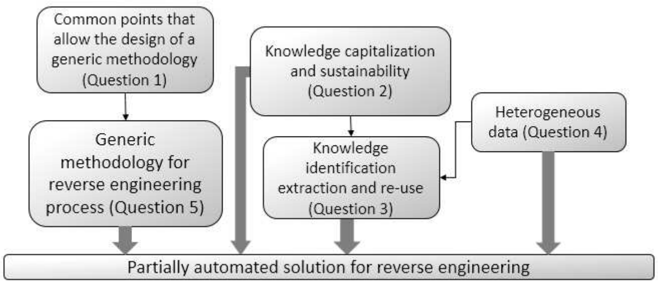

Fig. 6. Research methodology introduced in this paper

Figure 6 represents the imbrication of each research axis in order to address the global issue.

5. Case study: The METIS project

METIS is a French national project which aims to provide solutions for reverse engineering of large, complex mechanical assemblies. The main hypothesis of METIS is that raw geometrical data obtained with scanning sensors is insufficient to completely define and characterize complex mechanical assemblies. The main task of this project is to integrate all the available information and knowledge on the mechanical assembly studied in order to build up a rich digital mock-up, which can be used for different purposes (design, simulation, manufacture…).

The goals of the project are:

- If there is no digital mock-up, the goal is to allow the creation of a new digital mock-up with integrated implicit knowledge and rich semantics.
- If there is an old version of the digital mock-up, the goal is to allow the update of the bill of materials in order to have a digital mock-up configuration representative of the real object.

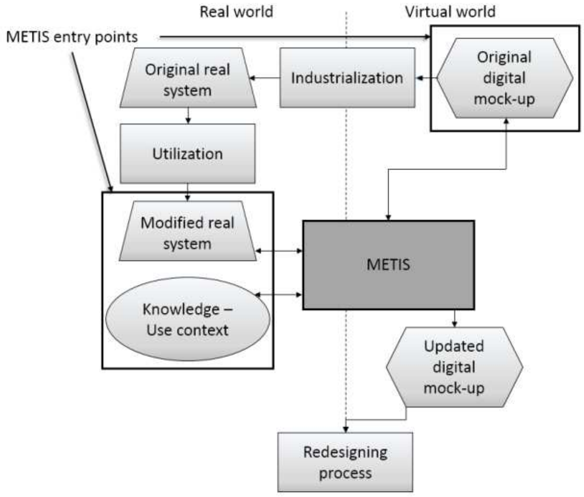

Fig. 7. Global process of the co-evaluation of a digital mock-up lifecycle and the system supported by the METIS project

Figure 7 introduces the positioning of METIS in the context of system lifecycle in which the structure, the knowledge associated and the digital mock-up change over time; the latter could exist or not at the beginning. Therefore, the inputs of METIS are the real system and the knowledge associated to the system at a given moment that is at our disposal. The output is the updated digital mock-up. This diagram illustrates also the particular case where a digital mock-up (generally 'old' in this case) of the product could exist, in which case this semantically high potential information should be used.

The main functions of the METIS project are the following:

- Acquisition, processing and integration of a large amount of data, geometrical or not, spatially located.
- Automatic components identification in a set of heterogeneous data.
- Browsing in the large amount of data, the possible bills of materials.
- Generation or modification of the digital mock-up.

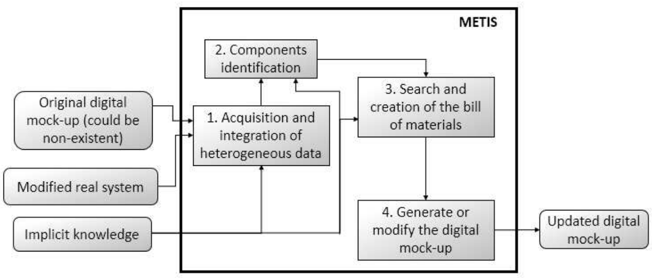

Fig. 8. METIS functions coherence

The functions of METIS are directly related to the research questions that have been asked:

Answering the first and fifth question will allow to create a methodology on which the general workflow of METIS will lie.

Answering the second question will allow to implement a knowledge management method which will allow the capitalization of knowledge that was unavailable in the knowledge structure.

Answering the third question will allow to implement algorithms of identification, search and extraction of knowledge.

Finally answering the fourth question will bring a methodology for the integration of heterogeneous data.

Conclusion

This paper presented a first prospecting of the integration of knowledge management approaches in a global reverse engineering methodology. The aim is to enhance the robustness of the reverse engineering process results, on one hand. On the other hand the context of automation.

At this stage we have identified 5 research questions through the Ishikawa methodology that define the perimeter in which will be developed the solution. A research methodology has been proposed in order to address the issues related to the questions identified. Finally, we introduced the project METIS which is a use case of the methodology in question.

Further work will deal with the development of a methodology of reverse engineering, which will have the heterogeneous data as guidelines. This methodology will be based on a knowledge management approach in order to extract knowledge from data and use it to reconstruct 3D parameterized models semantically rich.

References

[1] A. Bernard (1999), Reverse engineering for rapid product development: a state of the art, SPIE - The International Society for Optical Engineering, Three-dimensional imaging, optical metrology, and inspection V, Volume 3835, pp. 50-63 2

[2] F. Laroche, A. Bernard, M. Cotte (2008), Advanced Industrial Archaeology: A new reverse-engineering process for contextualizing and digitizing ancient technical objects, VPP, Vol. 3, N°2, pp.105-122.

[3] P. Benko, T. Varad. Segmentation methods for smooth point regions of conventional engineering objects, CAD, Vol. N°52, 2004, pp.36-511.

[4] N.Troussier, M.Bricogne, A.Durupt, F.Belkadi, G.Ducellier (2010). A knowledge-based reverse engineering process for CAD models management, IDMME-Virtual Concept.

[5] S. Remy, G. Ris, O. Nartz, A. Bernard (2003), Reverse engineering of a 1935 Delahaye radiator cap, European Virtual Engineering Network conference 2003, Dublin, Irlande, pp.107-115, ISBN 0-947974-15-6

[6] A. Bernard, O. Nartz, S. Remy, G. Ris, Y. F. Zhang, H.T. Loh, Y.S. Wong (2002), Reverse engineering and rapid prototyping, Software solutions for Rapid Prototyping, chapter 9, pp. 283-339.

[7] A.Durupt, S.Remy, G.Ducellier, B.Eynard (2008), From a 3D point cloud to an engineering CAD model: a knowledge-product-based approach for reverse engineering. VPP, 3(2), pp. 51-59.

[8] V.B.Sunil, S.S.Pande (2008), Automatic recognition of features from freeform surface CAD models. CAD. Vol.40, no 4, pp. 502-517.

[9] W.B.Thompson, J.C.Owen, H.J.de St Germain, S.R.Stark Jr, & T.C.Henderson (1999), Feature-based reverse engineering of mechanical parts. Robotics and Automation, IEEE Transactions on, 15(1), pp.57-66.

[10] VPERI Army research office virtual parts engineering research initiative, 2003. http://www.cs.utah.edu/gdc/Viper/Collaborations/VPERI-Final-Report.pdf.

[11] S.Musuvathy, D.Johnson, H.J.de St Germain, E.Cohen, X.Chimao, R.F.Riesenfeld, T.C.Henderson (2005). Integrating multiple engineering resources in a virtual environment for reverse engineering legacy mechanical parts. ASME IDETC and CIE.

[12] F.Laroche (2007). Contribution à la sauvegarde des objets techniques anciens par l'archéologie industrielle avancée. Doctoral dissertation, PhD thesis, Ecole Centrale, Nantes, 563 p.

[13] De Luca, L., Véron, P., & Florenzano, M. (2006). Reverse engineering of architectural buildings based on a hybrid modeling approach. CG, 30(2), pp.160-176.

[14] E.Mercier-Laurent (1997). Global Knowledge Management Beginning from Website: How to Organize the Flow of Knowledge in an International Company–Theories and Practice. ISMICK.

[15] I.Nonaka, N.Konno (1998). The concept of ba. Building a foundation for knowledge cration. CMR, n°40-3, pp.40-54.

[16] J.L.Ermine, M.Chaillot, P.Bigeon, B.Charreton, D.Malavieille (1996). MKSM, a method for knowledge management. ISMICK, Vol. 96, p. 288.

[17] G.Schreiber (2000). Knowledge engineering and management: the CommonKADS methodology. the MIT Press.

[18] A.Berger, J.P. Cotton, P.Mario (2009). Accompagner au début du 21ème siècle les organisations dans la mise en place d'une gestion des connaissances: retour d'expérience. et gestion des connaissances EGC.

[19] J.P.Poitou (1995). Documentation is Knowledge: An Anthropological Approach to Corporate Knowledge Management. ISMICK, Compiègne, France. pp. 91-103

[20] S.Chawathe, H.Garcia-Molina, J.Hammer, K.Ireland, Y.Papakonstantinou, J.Ullman, J.Widom (1994). The TSIMMIS project: Integration of heterogenous information sources.

[21] P.Buitelaar, P.Cimiano, A.Frank, M.Hartung, S.Racioppa (2008). Ontology-based information extraction and integration from heterogeneous data sources.International Journal of Human-Computer Studies, 66(11), 759-788.

[22] Son, S., Park, H., & Lee, K. H. (2002). Automated laser scanning system for reverse engineering and inspection. International Journal of Machine Tools and Manufacture, 42(8), pp. 889-897